Colorimetric and Resolution requirements of cameras

Alan Roberts

ADDENDUM 70 : tests and settings on a Canon EOS C300

Tests were made on a pre-production sample of the Canon EOS C300. Clearly, the specification and performance of the camera may differ when it is released, and therefore any details and measurements in this document are subject to modification, when a production model is tested. Canon have made it clear that this is only their first offering of a 'digital-cinema' camera.

The camera has one large CMOS sensor (super 35 size, 24.6x13.8mm) and uses interchangeable lenses. It will be available with one of two lens mounts, the standard PL, and Canon's EF range. EF lenses can be controlled from within the camera, while the PL mount has no electrical connections to the lens.

It records MPEG2-compressed video, and has HDMI and HDSDI output, but all the tests were made using the recorded MPEG2 signals, and analysed in software. It has a built-in monocular viewfinder, and connection ports for external LCD panel, control handle and other accessories.

The sensor is a single CMOS, total 4206x2340 photo-sites, of which a central patch of 3840x2160 is used for the video signal (the implications of this will be discussed in detail in the measurements section).. Recording is onto Compact Flash card (two slots) in MPEG-2, long-GoP, with MXF file format. Three bit rate options are available: 50Mb/s CBR (constant bit rate) at 4:2:2 colour sampling (1920x1080 or 1280x720), 35Mb/s 4:2:0 VBR (1920x1080 or 1280x720) and 25Mb/s 4:2:0 CBR (1440x1080 only). Thus it complies with broadcast requirements for bit rate and offers more economic rates for greater economy (the 25Mb/s option matches HDV format). At these rates, a 64GB card can record 160, 225 and 310 minutes respectively. In 1080 mode, both interlaced and progressive modes are available. Off-speed recording at fixed speeds from 12 to 60fps is possible. Recorded content is to 8-bit depth[1]; this is a limitation of the internal processing. HDSDI and HDMI outputs are also both 8-bit depth, although the data-stream is 10-bit. This does not appear to have any detrimental effect on the camera performance.

There is a conventional rear-mounted monocular viewfinder (specification 1.555Mpixels, about 1662x935 pixels). A larger accessory viewfinder (included in the kit) can be top-mounted on the camera, and adds significant extra controls to the camera. There is also an accessory side-mounted handle with record button. A WiFi dongle can be added, so that the entire camera can be monitored and controlled remotely from a laptop or suitable mobile telephone.

There are neutral filters for exposure control, and manual control of the lens. Sensitivity is good, and noise levels low. On-screen video level monitoring is good, there are options for both waveform monitoring and vectorscope. There is an image magnifier as a focus aid.

Connectivity is good, with HDSDI, HDMI and timecode, analogue HD luma signal or SD composite via BNC socket, and XLRs for audio via the accessory viewfinder module. Headphone and stereo microphones can both be connected via 3.5 mm jack sockets, independent of the viewfinder.

Power consumption is about 10.5 watts at 7.2 volts, rising to about 11.5 watts with the accessory viewfinder. There are 15 assignable (user) buttons. The bare camera weighs 1.43kg, which is fairly light for a large-format camera, although this figure can double when the camera is fully equipped with accessories.

The camera performed well under test.

[1] The EBU-approved 50Mb/s MPEG2 format is 4:2:2 coded at 10-bit depth. Although the camera records 8-bit content, it should be handled as 10-bit in post-production since this gives 'foot-room' for image manipulation without introducing colour contouring. No contouring was experienced during the camera tests.

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Many of the menu items have little or no effect on image quality. Those that have significant effect are highlighted. The full set of menu items is given for completeness. In boxes with a range of numeric settings, e.g. -99~+99, the values indicate the range, and zero means no alteration to factory setting, not zero effect, and no scales are given in the manuals. For each item, the factory setting is underlined. “Pref” (preferred) settings are in the last column, where appropriate, for normal video shooting and for film-look shooting. Where no preferred value is given, either the factory setting is best, or the setting does not have great effect on image quality. In some instances, it is possible to alter the menus such that they produce more meaningful numbers. Menus are nested: items in italics in the listing are headings leading to a further nested menu. The menu structure and contents are very similar to those of the XF300/305, and in many cases the same settings are appropriate

Camera settings which affect picture quality directly, such as gamma, detail and matrix are held in scene files. These are available via the CP button (Custom Picture) on the left-hand side of the camera, and adjusted by dial/button. Other functions such as gain and iris are also controlled by dial/button.

Settings are only starting points, recommendations. They should not be used rigidly, they are starting points for further exploration. However, they do return acceptable image performance.

Measurement results are given in section 2, after the menus. Measurements were made according to the procedures set out in EBU Tech.3335.

This listing of the menus and contents is complete, but this should not be used as an excuse for not reading the manuals. Not all menu items are available in both Camera and Media mode, and some items are missing in the PL version. Any such differences will be dealt with in a later test.

1 Menus and settings

CUSTOM PICTURE (i.e. scene file)

Main camera settings

Item	***Range***	***description***	***Pref***
Select File	Off, C1~C9, SD1~20	9 scene files, 20 on SD card.[2]	

Edit file			***Video***	***Film***
Rename	text	8 characters max		
Protect	Unprotect, Protect			
Reset	Cancel, OK			
Gamma	Normal1, Normal2, Normal3, Normal4, Cine1, Cine2,Canon Log, EOS Std	Transfer characteristic[3]	Normal 3	Cine1
Black				
Master Pedestal	-50~0~+50			
Master Black				
Red	-50~0~+50			
Green	-50~0~+50			
Blue	-50~0~+50			
Black Gamma[4]				
Level	-50~0~+50	+ expands blacks, - compresses	0	
Range	-5~0~+50		0	
Point	-1~0~+50		0	
Low Key Satur				
Enable	On, Off		Off[5]	
Level	-50~0~+50			
Knee				
Enable	On, Off	Highlight compression, not available in Cine gammas	On	
Slope	-35~0~+50		-2[6]	
Point	50~95~109	Lovely, IRE values!	85	
Saturation	-10~0~+10	Preserve colour in highlights	0	
Sharpness				
Level	-10~0~+50		+2	-3
H Detail Freq	-8~0~+8		+8	
Coring				
Level	-30~0~+50	To avoid sharpening noise		
D-Ofst	0~50			
D-Curve	0~8			
D-Depth	-4~0+4			
HV Detail Bal	-8~+8		+2	+5
Limit	-50~0~+50		0	
Select	0~15	Aperture correction[7]	+2	+15

[2] By default, files 1~6 are available for editing, 7~9 protected. 7=factory settings for video shown on consumer displays, 7=film-look on decent monitor, 9=video for printing to film. Protection can be removed for over-writing.
[3] Gamma curves: Normal 1=NHK 4.0, Normal 2=ITU709 4.0 (i.e. the 709 curve with lower slope near black), Normal 3=ITU709, Normal 4=BBC 0.4. Cine 1=film for video, Cine 2=for transfer to film, Canon Log needs special treatment in post, EOS Std matches Canon DSLR Standard gamma.
[4] Use Black Stretch sparingly, it enhances video noise.
[5] Low-key Saturation helps keep colouring right near black, but can worsen noise, use with care.
[6] Knee works well. This setting delivers about 1¾ stops extra headroom. Cine 1 gamma curve is good for a film look for television, and knee is disabled.
[7] This appears to be aperture correction, correcting for the basic spatial response or the camera, much more subtle than detail enhancement.

Item	*Range*	*description*	*Pref*	
Knee Aperture			*Video*	*Film*
Gain	0~9		[8]	
Slope	0,1~3		1	
Level Depend				
Level	0~50	Prevent sharpening near black	[9]	
Slope	0~3			
Offset	0~50			
Noise Reduction	1~12, Off, Automatic		Automatic[10]	
Skin Detail				
Effect Level	High, Middle, Low, Off	Soften skin tones		
Hue	-16~0~+16			
Chroma	0~16~31			
Area	0~16~31			
Y Level	0~16~31			
Selective NR				
Effective Level	High, Middle, Low, Off	Fine tune noise reduction[11]		
Hue	0~16~31			
Chroma	0~16~31			
Area	0~16~31			
Y Level	0~16~31			
Color Matrix				
Select	Normal1, Normal2, Normal3, Normal4, Cine1, Cine2, Canon Log, EOS Std	Preset matrices[12]	Normal 3	Cine 1
Gain	-50~0~+50			
Phase	-50~0~+50			
R-G	-50~0~+50		-8[13]	
R-B	-50~0~+50			
G-R	-50~0~+50			
G-B	-50~0~+50			
B-R	-50~0~+50			
B-G	-50~0~+50			
White Bal				
R Gain	-50~0~+50			
G Gain	-50~0~+50			
B Bain	-50~0~+50			
Color Correction				
Select	Off, Area A, Area B, Area A&B	Tweak two colours	Off	
Area A Setting				
Phase	0~31			
Chroma	0~31			
Area	0~31			
Y Level	0~31			
Area A Revision				
Level	-50~+50			
Phase	-50~+50			
Area B Setting				
Phase	0~31			
Chroma	0~31			
Area	0~31			

[8] Use Knee Aperture gain in conjunction with Knee Slope; as Knee Slope goes down, Aperture Gain can go up, to maintain sharpness.
[9] Use Level Depend in conjunction wit Black Stretch, to prevent over-sharpening near black.
[10] Very effective noise reduction, see measurements section. Setting to about 10 reduces resolution to 1280x720 very cleanly, but gives soft pictures, setting to 5 or 6 seems to be about right for 720p.
[11] Selective Noise Reduction could be useful but will take significant time to set up to be effective.
[12] Same rules as for gamma curves: Normal 1=NHK 4.0, Normal 2=ITU709 4.0 (i.e. the 709 curve with lower slope near black), Normal 3=ITU709, Normal 4=BBC 0.4. Cine 1=film for video, Cine 2=for transfer to film, Canon Log for best film-look, EOS to match Canon DSLRs.
[13] Matrix, see measurements section below.

Y Level	0~31		
Item	***Range***	***description***	***Pref***
Area B Revision			
Level	-50~+50		
Phase	-50~+50		
Others			
Setup Level			
Level	-50~0~+50	Scales Black and Master Ped	
Press	On, Off	Squeezes video to 100%	Off[14]
Clip 100% IRE	On, Off	Clips hard at 100%	Off
Transfer File			
Copy To	SD1~SD20	Copy current file to SD card	
Load From	SD1~SD20	Copy from SD card to current	
Copy To Cam	C1~C9		
Load From Cam	C1~C9		

[14] Press, not tested. This could be handy for shoot-and-run operations where exposure control is difficult.

CAMERA SETUP

Main video standard setting

Item	*Range*	*description*	*Pref*
ISO/Gain			
Select	ISO, Gain		
ISO increment	1 stop, ⅓ stop	320, 400, (500, 640), 800, 850[15], (1000, 1250), 1600, (2000, 2500),, 3200, (4000, 5000), 6400, (8000, 10000), 12800, (1600), 20000	
Gain	Normal, Fine	-6, -3, 0, 3, 6, 9, 12, 15, 18, 21, 24, 30dB Fine=0.5dB steps	
Iris			
Iris increment	½ stop, ⅓ stop, Fine		
Zoom-iris correct	On, Off	Correct ramping in known lenses	
Shutter			
Mode	Speed, Angle, Clear Scan, Slow, Off		
Shutter increment	⅓ stop, ¼ stop		
Cinema Locked	On, Off	Uses Canon Log, locks out the CP button	
ABB	Cancel, OK	Auto black balance, manual lens cap needed	
Color Bars			
Enable	On, Off		
Type	SMPTE, EBU, ARIB		SMPTE
Periph Illum Corr	On, Off	Correct vignette shading in known lenses	

AUDIO SETUP

Item	*Range*	*description*	*Pref*
Audio Input			
XLR Rec CH	CH1, CH1/2		
XLR1 Mic Trimming	+12, +6, 0, -6, -12dB		
XLR2 Mic Trimming	+12, +6, 0, -6, -12dB		
XLR1 Mic Att	On, Off		
XLR2 Mic Att	On, Off		
XLR ALC Link	Linked, Separate	Use link for stereo recording	
Limiter	On, Off	Limit at -4dB[16]	
1kHz Tone	-12, -18, -20dB, Off	Tone over colour bars	
Mic Mode	Automatic, Manual		
Mic Level	0~50~99	Manual level	
Mic Att	On, Off	20dB	
Audio Output			
Channel	CH1/2, CH1/1, CH2/2, All/All	All does mono mix	
Headphone volume	Off, 1~8~15		

VIDEO SETUP

Item	*Range*	*description*	*Pref*
SDI Output	HD, SD[17], Off	Off saves battery power	
Sync Output	HD-Y, HD Sync, Blk Burst[16], Composite[16], Off		
HD Onscreen Disp	On, Off	Puts camera screen messages on output, not on recording	
SD Onscreen Disp	On, Off		
SD Output	Squeeze, Letterbox, Side crop		

LCD/VF SETUP

Item	*Range*	*description*	*Pref*
LCD Setup			
Brightness	-99~0~+99		
Contrast	-99~0~+99		
Color	-20~0~+20		
Sharpness	1, 2, 3, 4		

[15] ISO 850 (or +2.5dB) delivers the optimum dynamic range, the 'sweet spot' and makes best use of matches Canon Log gamma.

[16] Manual audio controls (knobs): 0=off, 5=0dB, 10=+18dB

[17] 24P mode does not have an SD output.

Backlight	Normal, Bright		
VF Setup			
Brightness	-99~0~+99		
Contrast	-99~0~+99		
Color	-20~0~+20		
Sharpness	1, 2, 3, 4		
Backlight	Normal, Bright		
LCD/VF B&W	On, Off	On=mono	
LCD/VF Simul	On, Off	On=v/f and LCD on together	
View Assist	On, Off	Compensates for Canon Log gamma	
Peaking	On, Off		
Select	Peaking 1, Peaking 2	Two settable peaking regimes	
Peaking 1			
Color	White, Red, Yellow, Blue		
Gain	Off, 1~8~15		
Frequency	1, 2, 3, 4		
Peaking 2			
Color	White, Red, Yellow, Blue		
Gain	Off, 1~15		
Frequency	1, 2, 3, 4		
Zebra	On, Off		
Select	Zebra 1, Zebra 2, Zebra 1&2		
Zebra 1 Level	70, 75, 80, 85, 90, 95%	Active over ±5% of target	
Zebra 2 Level	70~100%	Active above target level[18]	
HD Output	On, Off	Show zebras on HD video outputs	
Markers			
Enable	On, Off		
Center	White, Gray, Off		
Horizontal	White, Gray, Off		
Grid	White, Gray, Off		
Safety Zone	White, Gray, Off		
Safety Zone Area	80, 90, 92.5, 95%		
Aspect Marker	White, Gray, Off		
Aspect Ratio	4:3, 13:9, 14:9, 1.66:1, 1.75:1, 1.85:1, 2.35:1		14:9[19]
Audio Level	On, Off		
Custom Display 1			
Custom Picture	On,Off		
Focal Length	On,Off		
ND Filter	On, Off		
Key Lock	On, Off		
White Balance	On, Off		
Iris	On, Off		
ISO/Gain	On, Off		
Shutter	On, Off		
Peaking	On, Off		
Magnification	On, Off		
View Assist	On, Off		
Custom Display 2			
Remaining Battery	Warning, Normal, Off	Warning=only when low batt	
Remaining Rec Time	Warning, Normal, Off	and so on	
Rec Mode	On, Off		
Genlock	On, Off		
Time Code	On, Off		
Interval Counter	On, Off		
SD Card Status	Warning, Normal, Off		
Bit Rate/Resolution	On, Off		
Frame Rate	On, Off		

[18] When zebra patterns overlap. Zebra 1 takes priority. This is perhaps the best use of zebras I've found in any camera yet.

[19] Not essential, but useful when shooting for mixed 16:9/4:3 delivery.

Character Rec	On, Off		
Output Display	On, Off		
SDI Rec Command	On, Off		
User Memo	On, Off		
Audio Output Ch	On, Off		
Audio Level	On, Off		
WiFi	On, Off		
Date/Time	On, Off	Only in playback mode	
Metadata Display			
Date/Time	On, Off		
Camera Data	On, Off		

TC/UB SETUP

Time-code and User Bits

Item	***Range***	***description***	***Pref***
Time Code			
Mode	Preset, Run		
Run	Rec Run, Free Run		
DF/NDF	DF, NDF[20]		NDF
Setting	Set, Preset		
TC In/Out	In, Out		
User bits			
Rec Mode	Internal, External		
Output Mode	Fixed, Pulldown		
Type	Setting, Time, Date		

OTHER FUNCTIONS

Item	***Range***	***description***	***Pref***
Reset			
All Settings	Cancel, OK		
Camera Settings	Cancel, OK		
Assignable Buttons	Cancel, OK		
Transfer Menu			
Save To	Menu, Menu+CP	Load save menus, or menus and all custom presets	
Load From	Menu, Menu+CP		
Time Zone	-12.00~+14.00		
Clock Set			
Date/Time	-		
Date Format	YMD, YMD/24H, MDY, MDY/24H, DMY, DMY/24H		
WFM (LCD)			
Setting	WFM, VS, Edge mon, Off		
Waveform Monitor	Line, Line+spot, Field, RGB, YPbPr	Spot adds waveform for the screen area in the red frame	
Gain	1x, 2x	+6dB gain	
Vectorscope	Spot, Normal		
Gain	1x, 5x	+14dB gain	
Edge Monitor	Type 1, Type 2	Focus aid, shows frequency content	
Gain	Off, 1~12~15		
Language	German, English, Spanish, French, Italian, Polish, Russian, Simplified Chinese, Japanese	Language for screen messages. Menus/settings remain in English	

[20] DropFrame timecode for recording at 'NTSC' speeds (59.94i, 29,97p, 23.98p).

Assign Button[21]	Camera mode Media mode	:None, Peaking, Zebra, WFM m(LCD), Edge monitor, Magnification, Color bars, Markers, LCD setup, VF setup, LCD/VF B&W, Onscreen display, Add shot mark 1, Add shot mark 2, Add OK mark, Add check mark, Time code, Time code hold, Headphone +, Headphone -, Audio output CH, Audio level, Photo, Func, Func Shutter, Func ISO/Gain, Func WB, My Menu, Initialize media, User setting none	15 assignables, marked: 1=Magnification 2=Peaking 3=Zebra 4=WFM LCD 5=Headphone + 6=Headphone - 7=Magnification 8=WFM LCD 9=Edge monitor 10~15 none	
Tally Lamp		On, Off		
Media Access LED		On, Off		
Genlock Adjust		-1023~0000~+1023	Horizontal phase	
24.00P[22]		On, Off		
NTSC/PAL		NTSC, PAL	Default value depends on where you bought the camera	
Relay Rec		On, Off	Seamless record across CF cards	
Double Slot Rec		On, Off	Record to both CF cards	
Bit Rate/Resolution		50Mb/s 1920x1080, 50Mb/s 1280x720, 35Mb/s 1920x1080, 35Mb/s 1280x720, 25Mb/s 1440x1080		50Mb/s 1920x1080[23]
Frame Rate	NTSC	59.94i, 59.94p, 29.97p, 23.98p		
	PAL	50i, 50p, 25p		
Special Rec		Interval rec, Frame rec, Pre rec, Slow & fast motion, Off	Non-standard shooting	
Interval Rec				
Interval		1~10, 15, 20, 30, 40, 50 sec, 1~10 min		
Rec Frames	23.98p, 24p, 29.97p, 59.94i	1, 3, 6, 9		
	25p, 50i, 50p, 59.94p	2, 6, 12		
Frame Rec				
Rec Frames	24p, 23.98p, 29.97p, 59.94i	1, 3, 6, 9		
	25p, 50i, 50p, 59.94p	2, 6, 12		
Slow & Fast Motion				
Rec Frame Rate	1080 24, NTSC	1~30	Variable speed shooting	
	720p 24,NTSC	1~30~60		
	1080 PAL	1~25		
	720 PAL	1~25~50		
Clips				
Title Prefix		AA~ZZ	Text entry	
Number Setting		Set, Reset		
Delete Last Clip		Cancel, OK		
Copy All Clips		Cancel, OK	Copy clips card to card	
Copy OK Clips		Cancel, OK	Copy only OK-marked clips	
Delete All Clips		Cancel, OK	Delete all except OK-marked	
Delete All OK Marks		Cancel, OK	Un-mark all cips	
Rec Review		Entire clip, last 4 sec	Play last 4 seconds of last clip	
Set Metadata				
Setting		Remote, SD card		
User Memo			List of memos on the card	
Country Code		4 letters	Entre label, A~Z, 0-9 +-; and space	
Organization		4 letters		
User Code		4 letters		
SDI Rec Command		On, Off		
Photo Numbering		Reset, Continu		
Delete All Photos		OK, Cancel	Wipes the SD card	

[21] 15 buttons assignable in Camera mode, 9 in Media mode.
[22] Beware, this is genuine 24.00P, not 23.976P, so there is no SD output, and timecode is NDF.
[23] This is the minimum coding specification accepted for EBU broadcasting at the time of writing this report (December 2011).

Add CP File			
To Clip	On, Off	Copies settings to clip or photo as metadata	
To Photo	On, Off		
Custom Function			
Shockless Gain	On, Off	Auto gain control	
Control dial	Iris, ISO/Gain, Off		
Control Dial Dir	Reverse, Normal		
Grip Contr Dial Dir	Reverse, Normal		
Select Dial Dir	Reverse, Normal		
F. Assist B&W	Both, Magnify, Peaking, Off		
Scan Reverse Rec	Both, Vertical, Horizontal, Off		
Character Rec	On, Off		
Reset Hour Meter	Cancel, OK		
WiFi R more			
Setup New		Details are in a separate Canon PDF file	
Select			
Edit			
Camera Settings			
Initialization			
CF A	Cancel, OK	Format card	
CF B	Cancel, OK		
SD Card	Complete, Quick		
Firmware		Shows firmware versions	
My Menu			
Register	Cancel, OK		
Move	Cancel, OK		
Delete	Cancel, OK		
Reset All	Cancel, OK		

2 Measurement results

2.1 Colour performance

Assessments were made visually, using Colorchecker charts as usual. Performance was generally good, but the skin-tone colours were a little pink, and the blues and reds oversaturated. Setting the matrix R-G value to about -8 should make some improvement, and there will certainly be more improvements to be gained by spending more time on this assessment, probably setting R-G to a negative value as well, and possibly using the colour corrector. This matter will be addressed more fully when a production model is tested. Overall, the performance was quite acceptable.

2.2 Gamma curves

There are 4 normal gamma curves available in the camera, and two Line curves, plus a Log curve and one to match Canon's EOS DSLRs. Clearly, the normal and cine curves are those of the XF300/305 and 100/105. For broadcast purposes either Gamma 3 (ITU-709) or 4 (BBC 0.4) is perfectly acceptable. The BBC curve always produces more accurate colour rendition, but the 709 curve is normal for HDTV shooting, so all further tests used Gamma 3 (ITU-709).

Experiments with the Knee function established that the camera has about 300% (1¾ stop) of exposure headroom at 0dB gain, when using the conventional gamma-correction curve. This setting is good for video shooting, but for film-look shooting, the Cine curves are better, and the Canon Log curve fully exploits the dynamic range but requires special treatment in post-production. With the Gain set to +2.5dB (ISO 850), Canon claim that the camera's dynamic range is fully used, at 12 stops.

2.3 Resolution

A HDTV zone plate chart was used. This contains six circular patterns that fully explore the spatial frequency performance of the camera, up to 1920x1080 pixels per width and height. There are patterns for grey-scale testing of luma performance, the others are coloured for examining chroma resolution or other colour filtering. Modulation is cosine rather than square wave. Each pattern is a "phase space" map of the possible frequencies that the camera can be expected to deal with, reaching 1920 pixels/picture width (960 cycles) horizontally, and 1080 lines/picture height (540 cycles) vertically.

2.3.1 Resolution, 1080psf

Figure 1 shows a single quadrant of one luminance pattern; for this exposure, the camera detail enhancement was turned down to minimum level (-10) which presumably means no correction, so this is probably the native performance of the camera. The lens was a Canon EF 24-70mm F/2.8L USM zoom. There are clearly no null zones, where the wanted lower frequencies mix with aliases produced by spectral folding of the unwanted higher frequencies, alias products. This is extremely unusual in a single-sensor camera, where the traditional Bayer-pattern mosaic of coloured filters must be decoded to provide a clean video signal.

Figure 1, Resolution, 1080p, minimum detail (-10)

It also implies that there is an optical spatial low pass filter between the lens and the sensor, to reduce the amplitude of spatial frequencies outside the band which can be properly dealt with for HDTV.

Figure 2 shows quadrants from the red and green patterns. Unusually, these show identical spatial

frequency responses, implying that the red and green signals (and therefore blue as well) all have identical bandwidths and sampling structures within the sensor. Figure 2 also shows the lower half of a smaller pattern which explores double the frequency limit of HDTV, revealing low level aliasing, both horizontally and vertically. This can only come from detail being delivered to the camera at up to 4k resolution, and shows that the optical spatial filter, while adequate for the job, still lets through some unwanted high frequencies. Whilst not expected to be troublesome, this implies that the use of lenses with higher detail performance might produce low-level aliasing as much as extra resolution.

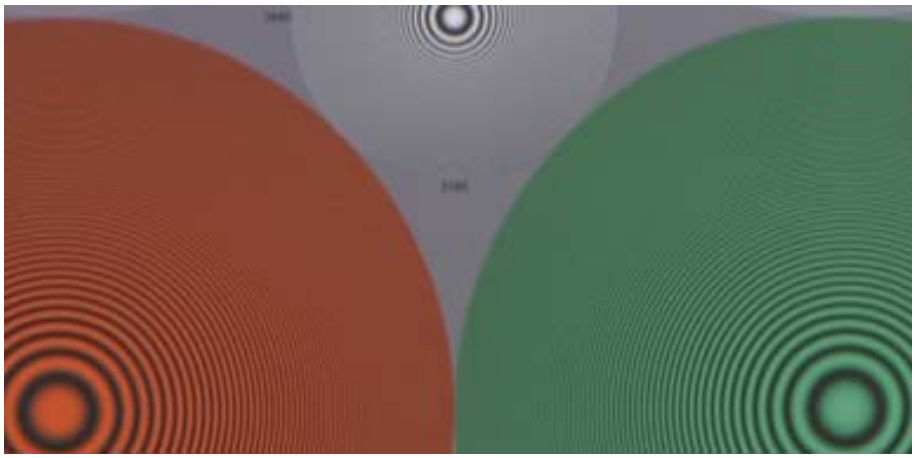

Figure 2, Resolution, 1080p, minimum detail, red and green

Clearly, this is not a 'normal' single-sensor camera. The camera's specification (that of the pre-production prototype, there is no mention of this in the full manual) claims that the sensor has 4206x2340 photo-sites, of which the central 3840x2160 are used to form video pixels. Since the viewfinder shows no image content outside the bounds of the video format, 1920x1080, it is safe to assume that the extra photo-sites are metal-covered to provide data for automatic and continuous black-level setting, although black balance can still be done on the active picture.

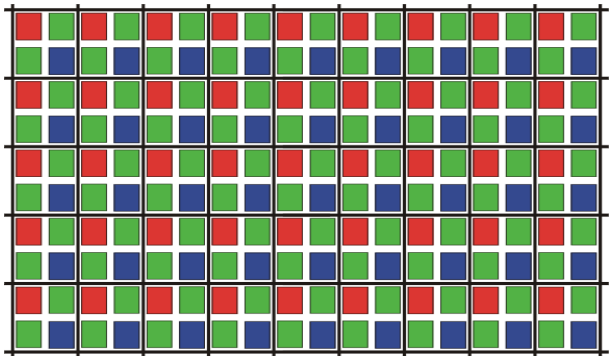

Figure 3, Bayer pattern, 1080 grid

Figure 3 shows part of the Bayer-pattern of photo-sites, with a grid structure for 1920x1080 superimposed. Clearly, within the area for each video pixel, there is one red photo-site, one blue, and two green. Potentially, there could be two different green filters, to tailor the colour performance, but that seems unlikely, since it would mean that this sensor was made specifically and uniquely for this camera. Given this simple relationship between photo-sites and pixels, the camera must be simply reading out the red and blue sites as red and blue pixels, and summing or averaging the two greens. Thus, each of red, green and blue have the same spatial resolution, unlike the performance when the Bayer pattern is decoded in an attempt to produce higher resolution. I have not seen this done in any other camera.

It is very rare to see resolution so clearly as this, which is very encouraging.

2.3.2 Detail enhancement, 1080p

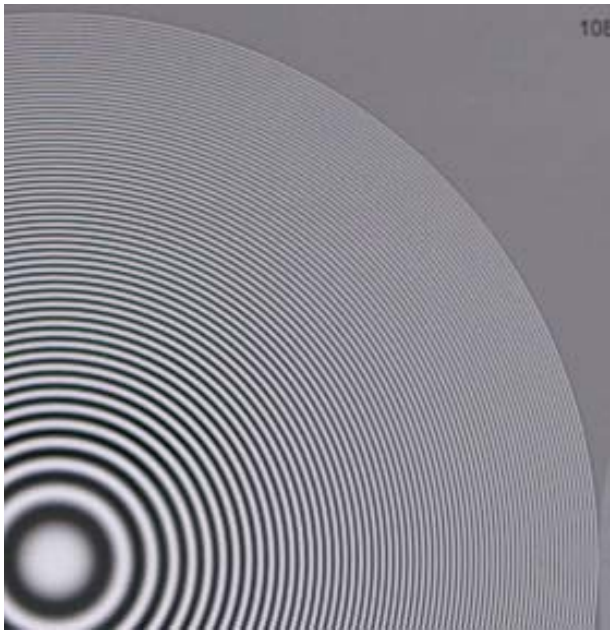

Figure 4, Resolution 1080p, detail=0

Detail enhancement can be quite severe, low levels are best. High levels of detail enhancement introduce null zones at 2/3 horizontal and vertical resolution limit, which are due to the small deviation of the camera gamma curve from a pure power law (this is third

harmonic distortion, emphasised by the detail enhancement), which is a perfectly normal phenomenon. At low detail levels, this effect is invisible.

Figure 4 shows the default level of 0, which is suitable for film-type shooting. There are faint null zones due to harmonic distortion, but the level is quite acceptable. Setting to +5 makes the picture a little sharper, suitable for normal video production.

2.3.3 Resolution, 1080i

Figure 5 shows the result of setting the camera to interlaced scanning, with the factory detail level setting.

Some vertical detail has been lost as is to be expected from the line-averaging process normally used for deriving interlaced fields, but it has been lost in a clean way, there are no surprises here. Interlaced performance is good.

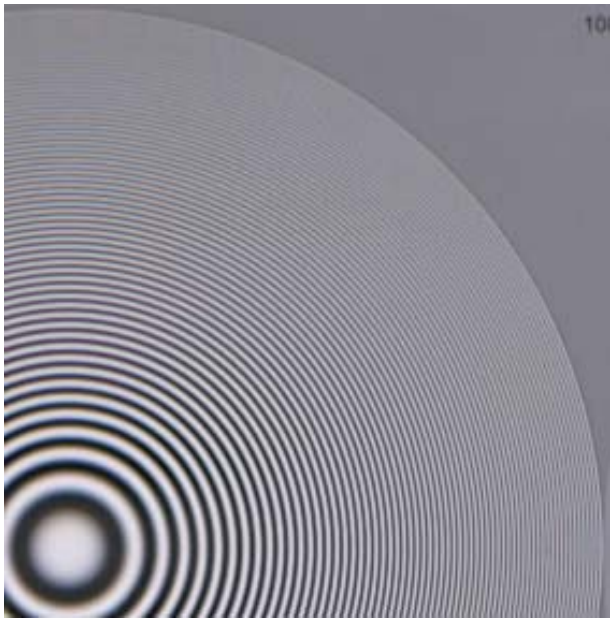

Figure 5, Resolution 1080i, detail=0

2.3.4 Resolution, 720p

Figure 6 shows the result of setting the camera to 720p/25 mode. Detail settings were set to factory values. There appears to no visible difference between the various 720p settings.

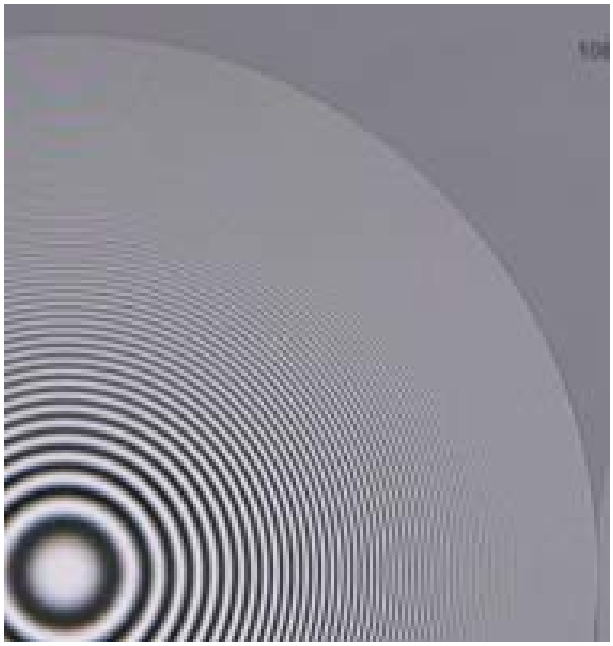

Figure 6, Resolution 720p, detail=0

There is a horizontal null zone at 1280 pixels, resulting from the down-conversion process. Ideally, all frequency content above this point should be suppressed, but the filtering used in the conversion process has clearly allowed some of this higher-frequency content through, and the aliasing is slightly coloured. Vertically, there is strongly coloured aliasing beyond 720 lines. This coloured aliasing is a little strange, and is a good indicator that there is something odd in the spatial down-conversion from the Bayer-patterned sensor to 1280x720.

Figure 7 shows the Bayer pattern with a 1280x720 grid superimposed. Each pixel group contains either 4 or 5 green photo-sites, 1 2 or 4 red, and 1 2 or 4 blue. Clearly, it is not possible to read from the sensor in a simple way to get a 1280x720 structure, and more complex processing is needed. In principle, it would be possible to sum relevant photo-sites in each pixel and normalise the values pixel by pixel, but this would produce a fixed pattern of coloured noise which would probably not be acceptable. There is little or no clue to how this processing is done, but it clearly involves some interpolation rather than the ideal spatial filtering (which would be far more complex and consume far more processing power and generate far more heat in the camera).

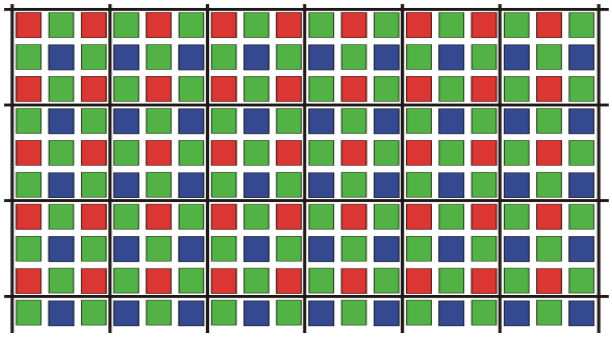

Figure 7, Bayer pattern 720 grid

However, there is way to set the camera such that 720p performance is more acceptable (this level of aliasing is not actually bad, but it could be better) (see section

2.4). Using this process, it makes sense to record 720p modes in the camera, rather than to use external hardware or software down-conversion.

2.4 Resolution with other lenses

Figure 8 shows the resolution, at 1080p, with two other lenses. Ignoring the small exposure difference, both lenses appear to deliver rather more resolution than the 24-70mm zoom, the macro being especially sharp. It might be sensible to reduce the detail level settings a little when using these lenses. The null zones at ⅔ horizontal and vertical resolution limits result from the default level of detail enhancement and are not remarkable.

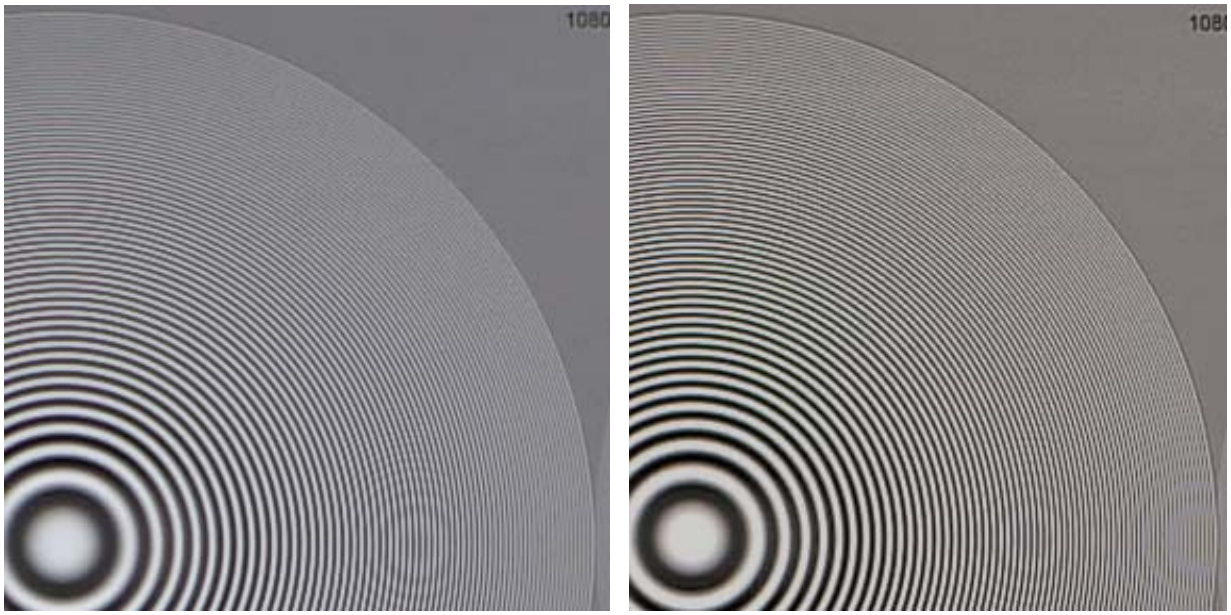

Figure 8, Resolution 1080p, a) 50mm prime F/1.2 b) 100mm macro

2.5 Video Sensitivity and Noise Levels

Sensitivity was measured by evenly illuminating a white card at 2000 lux, and setting camera gain to 0dB. The lens aperture to produce peak white was F/10 at 1080p25. This agrees precisely with the specification. It is very similar to that of conventional 3-sensor cameras of ⅔" format, and hints that the camera internal analogue gain has been set quite low, to deliver high video headroom and low noise.

Video noise was measured by recording a defocused white card, uniformly lit, and performing numerical analysis in software. Standard Gamma 3 was used, ITU-709.

The camera was initially set to -6dB gain to determine the best possible results from the camera. A high-pass filter was used to remove all horizontal frequencies below about 5% of the nominal maximum of half-sampling frequency. Figure 9 shows the results, noise level in dB plotted versus signal level. Normally, the distribution would follow the slope of the gamma curve, which would produce 14dB more noise near black than near white. Although these results follow the general trend of the gamma slope, they do not fit it well. This could be the results of attempts to optimise the use of digital processing by using non-linear ADCs (i.e. performing some form of pre-gamma-correction on the analogue signals from the sensor). Since the camera's digital processor handles only 8-bit signals at the output, it may not be handling

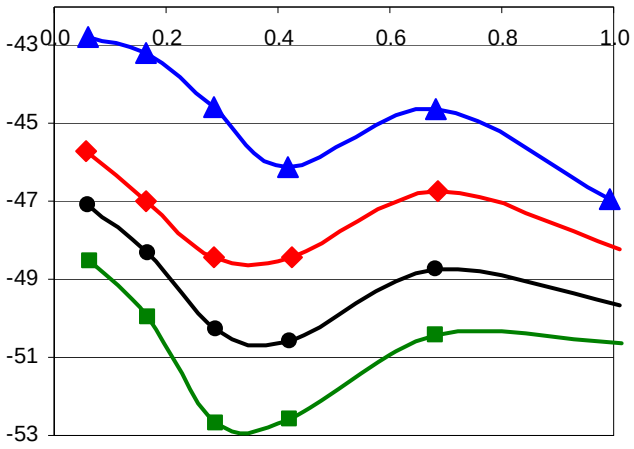

Figure 9, Noise distribution, 1080p, -6dB gain

more than 10-bit data at the ADCs, and so non-linear ADCs make a lot of sense. It is clear that a better digital processor would result in significantly lower noise values in this camera. However, this non-uniform distribution of noise gives the pictures a more film-like appearance, where the pictures appear to be 'more quiet' than the numerical analysis alone would indicate.

The measured noise levels are not low enough to be limited by the 8-bit nature of the recorded signal, which has a noise floor of about -54dB. The camera's performance appears to be well-matched to 8-bit output.

The significantly-better performance in green than in red and blue is probably due to the effectively-double size of the photo-sites for green. The specification claims the sensor size to be 24.6x13.8mm, super35 format, meaning that the photo-sites must be spaced at 6.4µm intervals, compared with 5 µm for a conventional ⅔" 3-sensor camera. If we set aside the 'dead' areas of the sensor (that covered by metal or non-light-sensitive electrodes) then the red and green pixels have photo-sites of 41 μm^2 compared with 25 μm^2 for a ⅔" 3-sensor camera, i.e. about 5.1dB greater area, while the green pixels each have 2 such photo-sites and a total area of 82 μm^2 i.e. about 10.2dB increase. Allowing for lower head-amplifier gain (say 9dB) to deliver increased headroom (800%), we could expect the green channel to match ⅔", and the red and blue to be 6dB worse. The measured noise values appear to justify these expectations.

Next, the lens and neutral filters were adjusted in conjunction to maintain a video signal level of 50%, while the gain was varied from -6dB to +30dB (corresponding to ISO320 to 20,000). Figure 10 shows the results, noise level vertically versus camera gain horizontally.

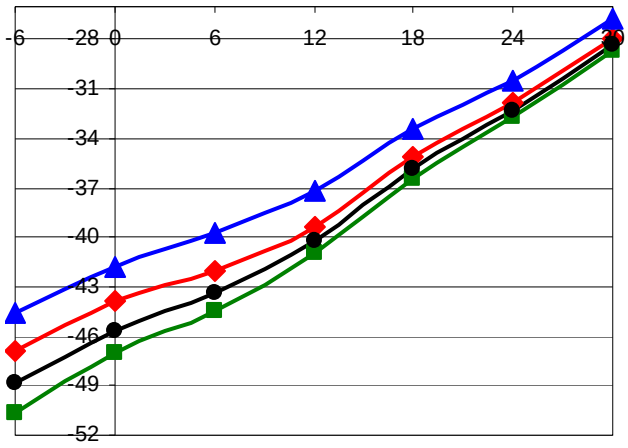

Figure 10, Noise distribution, 50% signal level

The curves all follow the same slope, where the noise level increases by about 3dB for each 6dB change of video gain. This is inevitable where the gain is applied in the analogue signal, since 6dB gain doubles the signal level, but only doubles the noise power rather than noise voltage, thus 0.5dB/dB is the expected slope of the curves. Even at +24dB gain (ISO5000), the noise level is acceptable, -32 to -33dB. It is clearly visible in the pictures, but not obtrusive. At +30dB gain, the noise level may well be unacceptable for serious programme-making. However, overall, the performance is quite acceptable. Note that the smooth slope of the curves continues to the lowest gain levels. This implies that the 8-bit nature of the recorded output is not affecting the noise performance, i.e. that the noise floor of the system is not affecting things.

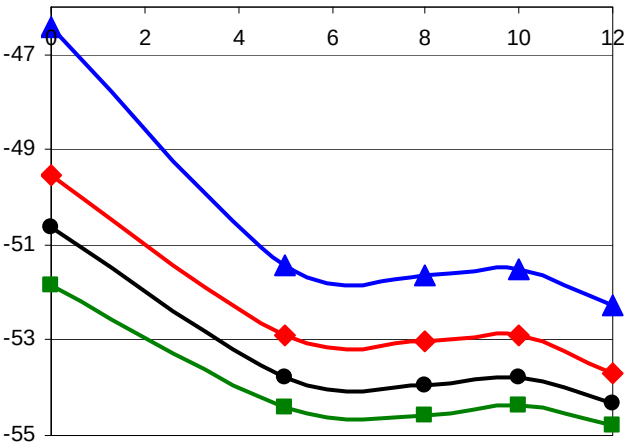

Figure 11, Noise reduction

Video noise reduction is available in this camera. There is a noise advantage of about 1.5dB to be gained from setting it to Automatic mode, and this has little or no visible effect on resolution. However, it should be borne in mind that this advantage is when the camera is set to +12dB gain, and that the advantage should be rather less at 0dB gain. Nevertheless, the noise reduction is worth having, and it is only with noise reduction that the specified noise level of -54dB is reached.

Figure 11 shows how its use affects the noise levels when the camera is set to -6dB, where the user is expected to be most critical. There is about 4dB advantage to be had by using level 4, while setting to greater than about 5 produces relatively little improvement. However, it should be borne in mind that this noise reduction is done by intra-frame filtering, which reduces the resolution. Therefore, using higher levels should be avoided when shooting at 1080, unless extremely high-gain settings are essential.

This filtering can be a positive benefit when shooting at 720p, since it reduces the higher frequency content which causes the spatial aliasing shown in Figure 6. The spatial filtering, at high levels, can be quite severe. Figure 12 shows the effect of setting noise reduction to level 10 on a 720p image. There is significant softening, although not enough to eliminate the spatial aliasing. Therefore, although the filtering helps, there is no point in setting it to a high level since it does not dramatically lower the noise level and does not eliminate aliasing. Setting to about 5 or 6 seems to be optimum for use at 720.

Figure 12, Resolution 720p, Noise reduction=10

2.6 Dynamic range

The specification claims the dynamic range to be 12 stops at ISO850 (+2.5dB gain), and that this is the sweet spot for handling headroom, at 800% (3 stops). Testing this is rather difficult, since the Canon Log gamma curve must be used and interpreted in post-production. At the time of testing, the data curves were not available, therefore I set the camera to ITU-709 gamma curve with knee switched off, to see what could be done within a conventional gamma curve.

A white patch was illuminated with the camera set to +12dB gain, and the exposure varied using the iris and neutral filters to determine the transfer characteristic. Figure 13a shows the results, signal level plotted versus exposure level with linear axes. However, the most interesting part is near black, so it makes more sense to plot the data with a logarithmic horizontal (exposure) axis, as in Figure 13b. Note that the vertical axis remains linear, and that the slope of this curve must be the numerical value for the power law of the characteristic, assuming that it genuinely has one. It is clear that, when the signal level is below 10% (0.1), the curve is becoming more shallow, this is the linear part of the ITU-709 curve, and is expected.

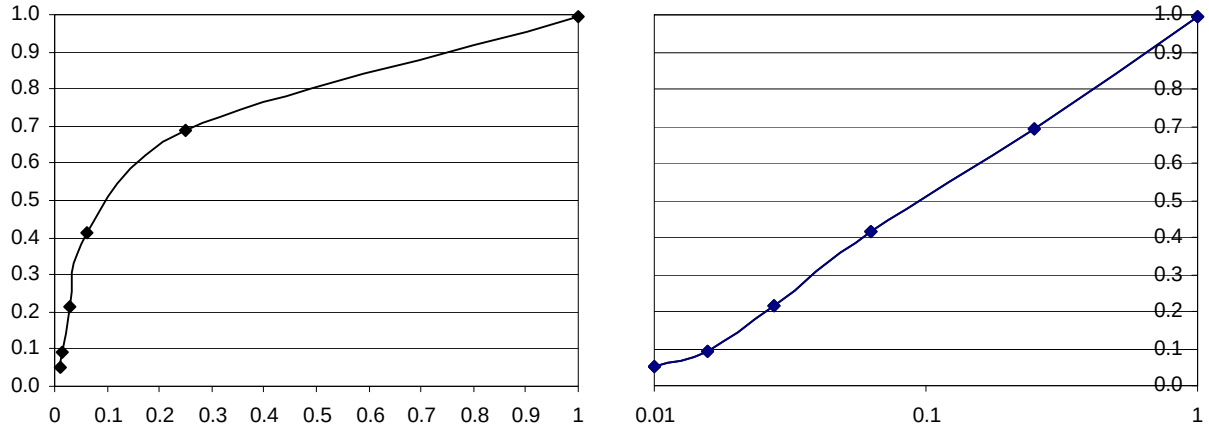

Figure 13, Dynamic range, a) linear plot **b) logarithmic plot**

During the capture process, the very lowest exposure capture produced an image which was barely distinguishable from the background on two LCD monitors, had disappeared on a third, and was only just visible on a Sony 32" Grade 1 CRT HD monitor. It was also only just distinguishable from the background on a waveform monitor. Since this exposure was 10 stops below that for peak white, we can state that the exposure range is between 9 and 10 stops using the normal gamma curve, but can be extended by a further 1.75 stops by using the recommended knee settings. Therefore the range is about 9.5 stops with normal gamma-correction, extending to 11.25 stops with optimised knee.

If, as Canon claim, the camera's sweet spot is at ISO850/+2.5 where there is headroom of 800% (3 stops), this would stretch the available exposure range to 12.5 stops, but this is available only by using the Canon Log gamma-correction curve.

2.7 Shuttering

The camera has a CMOS sensor, and thus is expected to exhibit the effects of a rolling shutter. A motion sequence was recorded, of a small rotary fan with six equal segments having straight, radial, edges. The camera shutter was set to 1/1000 in order to sharpen the images.

Figure 14a is a frame from that sequence, which clearly show geometric distortions (since the top of the frame is exposed significantly before the bottom). The fan speed was adjusted to one of several critical speeds at which a stroboscopic effect was observed. The blades are compressed when on the left (going up, against the shutter), grossly expanded on the right (going down, overtaking the).

The observed effect is rather less than has been seen on other CMOS cameras, clearly this sensor is not being scanned in the conventional way, at video scanning speed. It seems most likely that the sensor is being scanned at higher speed into a store, possibly in about 5msec instead of the more usual 20msec for a 25p video frame. Short of complete and expensive redesign of the scanning process, this is probably about good as can be done at this price.

If the shutter is set to a more sensible speed (1/50, Figure 14b), then the effect is far less disturbing, but the blurred blades still appear to be asymmetrical, being swept to the left. This combination of sloping verticals and distorted rotating elements may not often occur in programme-making, but the effects can be disturbing when they occur by accident. However, this camera performs rather better than others with CMOS sensors.

Figure 14, Rolling shutter effect, a) 1/1000 b) 1/50

2.8 Conclusion

This camera performs well. Resolution is very well maintained and is refreshingly alias-free, far more so than other CMOS single-sensor cameras. Detail controls work well, and the factory settings are generally good. Noise levels are similar to those of ⅔" cameras with 3 sensors, as is sensitivity. Dynamic range is unusually high, at least 12 stops. Operating the camera at significantly higher gain produces more noise, but not dramatically so. The specified noise level of -54dB is achievable only at -6dB gain and with noise reduction switched on. Noise distribution is non-uniform, which gives the pictures a more film-like appearance.

Because of the large-format size of the sensor, iris diffraction should not start to be visible until the lens is stopped down to between F22 and F32. This, together with the integral neutral density filters, means that there should be about 14 stops of useful exposure control.

Performance at 720p is acceptable although not quite ideal, and can be improved a little by judicious use of the noise reducer. It is probably not essential to shoot at 1080 and use an external software or hardware down-converter, although the resulting spatial aliasing would probably be better by doing so.